CHAPTER 8

Conclusions and Suggestions for Future Research

8.1 Conclusions

The aim of this thesis in analysing the performance of indoor infrared links and proposing implementation issues and protocol modifications that improve the operation of short range infrared links has been achieved. Two protocol stack proposals developed by the Infrared Data Association (IrDA) have been considered; the widely used IrDA 1.x proposal for indoor point to point links and the recently developed AIr proposal for indoor infrared LANs. The following protocol stack layers have been studied:

- IrDA 1.x IR Link Access Protocol (IrLAP)
- Advanced IR Medium Access Control layer (AIr MAC)
- Advanced IR Link Control layer (AIr LC)

The main contributions of this thesis are:

a) The derivation of simple equations that calculate optimum values for the window size and frame length link layer parameters of the IrDA 1.x protocol. These optimum values can be implemented easily in order to maximize the performance in high BER point to point IR links.

b) The proposal of link layer parameters and retransmission scheme that maximize the performance for a specific link quality in indoor AIr LANs. This work also considers the network scenarios that render AIr connectivity beneficial.

8.1.1 Conclusions for the IrDA 1.x IrLAP

a) The link turn around time due to hardware latency is of key importance in IR point to point links as it may significantly decrease performance. Two proposals are considered to address this problem in high speed IR links: a) the employment of IR ports with smaller hardware latency time periods and b) the implementation of higher window sizes (from 7 to 127 frames) at the link layer in order to reduce the link turn-around frequency. High window size employment increases performance at low BER, especially when link turn around time is high. The price we pay for using high window sizes is that link performance becomes sensitive to BER increase because an error frame causes the retransmission of a significant number of out of sequence frames.

b) The maximum value for the minimum turn around time parameter of the future IrPHY specifications (40 Mbit/s or 100 Mbit/s) should not be less than 0.1ms when the IrDA links are expected to operate in good conditions of low BER. In this case, IrLAP should utilize the maximum allowed window size of 127 frames. If it is desired that the future high speed links should be more robust to BER increase, then a lower value of 0.01 ms should be defined for the minimum turn around time parameter. In this case, IrLAP should utilize the maximum window size of 127 frames at low BER and a reduced (or optimum) window size value when BER increases.

c) The implementation of optimal window and frame size values simultaneously results in maximum utilization and significant performance improvement, especially at high BER links. The minimum turn around time (hardware latency) and the F-timer time-out period are the main detrimental factors on performance in this case. Reducing the hardware latency of the IR ports significantly improves utilization.

d) The following modification in IrLAP operation is proposed to address delays arising from the F-timer expiration when optimum window and frame size values are implemented. The transmitter should not pass transmission control by setting the P-bit in the last I-frame it transmits, but set the P-bit in a new Receive Ready (RR) S-frame that follows the last I-frame transmission. This modification successfully minimizes delays arising from F-timer expiration at the expense of a small RR frame transmission and improves utilization. The implementation of simultaneously optimal window and frame size values, combined with the S-frame modification and IR ports with small hardware latency results in significant IrLAP performance figures on high BER links.

e) When optimal window and frame size values are simultaneously implemented, the optimum frame size values balance the time consumed on retransmitting error frames with the time consumed on transmitting overheads; the optimum window size values balance the time utilized in retransmitting out of sequence frames with the time utilized on acknowledgments.

f) Implementation of optimum window and/or frame size values is very simple and effective if the transmitter implements optimum values based on its estimation of link BER. Simulation results indicate that if the transmitter implements (a) only eleven different sets for both optimum window and frame size values, (b) simple rules for estimating link BER and (c) both optimum window and frame size values, a significant and very close to the maximum IrLAP performance can be achieved.

8.1.2 Conclusions for the AIr standard

a) AIr applications should utilize a high window size and the maximum frame size (16Kbits) at the MAC layer in order to achieve high channel utilization. The reason is that the essential PHY and MAC information transmitted in the Robust Header field of the reservation control frames is always transmitted using maximum Repetition Rate (RR=16) to ensure maximum coverage. As a result, the time required for medium reservation is increased and the transmission of significant amounts of information data during successful reservations is necessary for high utilization. The proposed Collision Avoidance procedures perform very effectively; these procedures include the Contention Window adjustment algorithm and the large Collision Avoidance Slot (CAS) duration that avoids collisions from hidden stations.
b) When there are no hidden stations, the proposed lower and upper limits for the Contention Window (CW) size result in utilization degradation. The lower limit of 8 slots should be lowered to 1 and the upper limit of 256 should also be lowered to 65. The proposed upper limit value of 65 corresponds to 21 backoff stages (65=1+21x4), when every stage utilizes the contention window size of the previous stage increased by 4. The new lower limit results in significant utilization improvement when one or a few stations are transmitting in the LAN.
c) The proposed Repetition Rate (RR) coding is proven very effective in reaching stations with low Signal to Noise Ratio (SNR). Doubling RR provides a 3-4 dB gain in SNR. The frame error rate (FER) threshold that renders doubling RR beneficial depends on the employed retransmission scheme. Assuming that RR coding is effectively implemented and the optimum RR value that results in maximum link utilization for a station’s SNR is utilized:
   i) if the application utilizes a small payload window size, the Reserved transfer

mode with sequenced data at the MAC layer should always be employed.

ii) if the application utilizes a high payload window size, the Reserved transfer mode with sequenced data at the MAC layer is usually the best choice. However, for certain SNR values, the Reserved transfer mode with acknowledgment achieves a higher utilization.

d) When the MAC SW ARQ scheme is utilized, the LC GBN ARQ scheme should be disabled and the LC layer should rely on the MAC SW scheme to guarantee that the transmitted information is correctly received by the remote station. Implementation of the GBN ARQ scheme at the LC layer, which is very close to the MAC layer, results in significant delays and no significant benefits.

e) When a reliable information transfer procedure is not utilized at the MAC layer and the LC layer implements its GBN ARQ scheme, the LC layer should poll the remote station by setting the P/F bit in a special Receive Ready acknowledgment (LC ACK) frame and not in a data frame. The reason is that the LC ACK frame is very small, it is seldom lost and significant delays caused by a possible P/F bit loss are avoided. The delay for the additional LC ACK frame transmission is very small compared to other protocol delays, such as the transmission time of control frames, TAT delays and contention periods.

f) If RR coding is not employed and a small window size is utilized, the transmitter should always employ the Reserved transfer mode with sequenced data at the MAC layer. If a high window size is utilized, the Reserved transfer mode with sequenced data at the MAC layer is again the best choice for error free links. For links with transmission errors, applications utilizing high window sizes should employ the Reserved transfer mode with acknowledgment at the MAC layer. In all cases, the LC layer retransmission scheme should be disabled.

g) Unreserved transfer mode should rarely be used at the MAC layer, especially in LANs with many transmitting stations. Unreserved transfer mode incurs the least overhead because it does not reserve the infrared medium using the RTS/CTS control frame exchange. However, if a data frame in the Unreserved mode collides, the remaining stations are unaware of the collision because the AIr physical layer does not indicate the medium busy condition. Contending stations transmit during the collision causing a fairness problem and utilization degradation.

8.2 Suggestions for future research

a) Collision avoidance procedures with hidden stations: In this thesis, an analytical model for the collision avoidance scheme of the AIr protocol is developed for WLAN scenarios with no hidden stations. As the presence of hidden stations is probable in infrared WLANs, the development of an analytical model that evaluates the performance of the collision avoidance procedures considering hidden stations is an open challenge. Such an analysis could examine the suitability of the proposed values for minimum and maximum CW size parameters for all network scenarios. The proposed analysis could also evaluate the implications of hidden stations for medium access delays and on ARQ scheme and RR value selection for AIr WLANs.

b) The presented analysis for the IrDA 1.x performance confirms that the implementation of optimum window and frame size values significantly improves the performance of point-to-point links at high BER. The AIr protocol introduces significant turn around delays arising from the collision avoidance procedures and from the RTS/CTS/EOB/EOBC frame exchange. In addition, it implements RR coding to cope with transmission errors. The derivation of optimum window size, frame length and RR value that maximize performance for the proposed ARQ schemes in the AIr protocol is an open issue. The AIr protocol stack implements receiver's recommendations of the RR value the transmitter should implement for maximum performance. The receiver may also recommend suitable window and frame size values that the transmitter should implement. Such an analysis will reveal the effectiveness of adapting window and frame size to cope with transmission errors in infrared multipoint wireless communications.